COMPONENT PART NOTICE

THIS PAPER IS A COMPONENT PART OF THE FOLLOWING COMPILATION REPORT:

TITLE: Minutes of the Explosives Safety Seminar (21st) Held at Houston, Texas on 28-30 August 1984. Volume 1.

TO ORDER THE COMPLETE COMPILATION REPORT, USE AD-A152 062.

THE COMPONENT PART IS PROVIDED HERE TO ALLOW USERS ACCESS TO INDIVIDUALLY AUTHORED SECTIONS OF PROCEEDING, ANNALS, SYMPOSIA, ETC. HOWEVER, THE COMPONENT SHOULD BE CONSIDERED WITHIN THE CONTEXT OF THE OVERALL COMPILATION REPORT AND NOT AS A STAND-ALONE TECHNICAL REPORT.

THE FOLLOWING COMPONENT PART NUMBERS COMPRISE THE COMPILATION REPORT:

AD#: P004 821 thru P004 861 AD#: ____

AD#: ____ AD#: ____

AD#: ____ AD#: ____

Accession For	
NTIS GRA&I	☑
DTIC TAB	☐
Unannounced	☐
Justification	
By	
Distribution/	
Availability Codes	
Dist	Avail and/or Special
A-1	

DTIC FORM 463 MAR 85

OPI: DTIC-TID

AD-P004 829

METHOD OF PREDICTION OF THE EXPLOSIVE BEHAVIOR OF HIGHLY CONFINED PBXs SUBMITTED TO BULLET IMPACT

Presented to :

21st Department of Defense
Explosive Safety Seminar

August 28, 1984
to
August 30, 1984

by

Philippe MONTEAGUDO

SOCIETE NATIONALE DES POUDRES ET EXPLOSIFS
CENTRE DE RECHERCHES DU BOUCHET
91710 - VERT LE PETIT
FRANCE

METHOD OF PREDICTION OF THE EXPLOSIVE BEHAVIOR OF HIGHLY CONFINED PBXs SUBMITTED TO BULLET IMPACT.

Author : P. MONTEAGUDO , SNPE , FRANCE

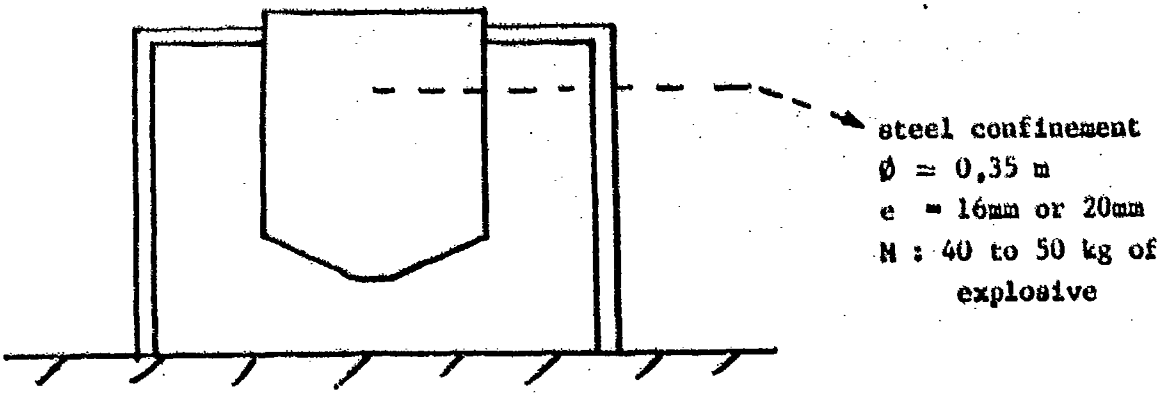
Abstract : We describe the mechanisms which govern the bullet impact reactivity of strongly confined castable plastic bonded high explosives. We point out the parameters which drive the reaction. This ~~one~~ is a deflagration to detonation transition, in the studied cases.

We succeed in elaborating a first practical model, able to forecast the explosive behavior of castable plastic bonded high explosives (based on the fragmentability of the explosive material) and strongly confined.

1. ORIGIN OF THE NEED AND STAKE.

Since 1973, the need expressed by French Navy to have bullet insensitive military warheads, has led to realize large scale experiments on warheads charged with PBXs.

The experiment configuration was as follows :



The PBX of the charge was made up of 14 % of polyurethane binder and of 86 % of octogen.

The stress was the following :

- bullet : caliber 13,2 P
- velocities : 700 to 825 m/s

The results obtained could be listed as follows :

- nothing (no reaction)
- combustion
- deflagration
- extremely violent reaction occuring after varying lapses of time and lasting sometimes several minutes.

In order to get a better understanding of the situation we have undertaken a study with the aim to identify the reactive mechanisms, so that we could improve the behavior of warheads to bullet impact.

The stake is very important because the results of this work may allow :

- to foresee a priori the behavior of a military warhead to the bullet impact.
- to define some compositions of confined explosives that would be less sensitive or insensitive to this impact.

This study consists of two main lines :

1. - a theoretical line : to realize a numerical modelling of the behavior of a body composed of steel and of explosive to the bullet impact .
2. - an experimental line : to research a configuration on a small scale allowing to reproduce the results obtained on a large scale.
   - to identify the parameters that govern the reaction.

2. NUMERICAL MODELLING.

2.1. Hypothesis of calculation and modelling.

In order to bring the actual problem to a configuration that could be dealt with by the HEMP code (three dimensions with axial symmetry) we have given a cylindrical geometry to the target and we have made the trajectory of the bullet meet the axis of symmetry of the device.

We were also led to simplify the form and the composition of the bullet.

The planes and grooves have not been taken into account and the bullet has been given a geometrically sharp form (figure 1). From its actual components we kept only the steel, wich volumic mass was modified (7,85 g/cm3) in order to obtain an identity of the masses (45 g).

The velocity of the bullet is of 833 m/s.

The target is 16 mm thick and its radius is 100 mm. Its mass is of 3946 g.

The explosive is 30 mm thick for a radius of 100 mm.

The axis of the bullet must always meet the axis of symmetry of the target.

It is also considered that the coating and the explosive must slip on the bullet without having the possibility to create a vaccuum or a punching.

These two materials are supposed to be strictly interdependent at the level of their interface (hypothesis of a perfect stricking).

The explosive (14% of polyurethane binder and 86% of octogen) is supposed to behave in a hydrodynamic way on account of the strong stresses that we can expect. It is also supposed that the minimal pressure withstood in traction is equal to zero.

The state equation is a form of the HUGONIOT equation :

$$p = \rho_0 \frac{a^2 (y - 1)}{[y - b (y - 1)]^2}$$

where P is expressed in Megabars and y is the reverse of the relative volume $\frac{V}{V_0}$, and with :

$\rho_0 = 1.71$ g/cm3
a = 0.2071 cm/s
b = 2.309 (without dimension).

The steels of the bullet and of the protective coating are described by a perfect elastoplastic behavior. No rupture criterion was used during the modelling.

- Characteristics of the coating :
  It is a tempered steel :
  elastic limit Y = 9500 bars,
  modulus of shearing off G = 0.815 Megabar
  modulus of compressibility K = 1.65 Megabar
  volumic mass $\rho_0 = 7.85$ g/cm3,

- Characteristics of the projectile :
  They are identical to those of the coating, except for the elastic limit : Y = 9000 bars.

The state equation selected for these two materials is the following :

$$P = 1.65\ (y - 1) + 1.87\ (y - 1)^2$$

where P is expressed in Megabar and where y is the reverse of the relative volume.

The velocity of the elastic waves, calculated with the above data, is :

A = 5904 m/s.

2.1. The results.

The calculations have been made from the impact, taken as the zero hour, up to 54 μs, at which moment the bullet started to penetrate the explosive.

Figures 2 to 5, given in appendices,describe the history of the pressure in various places of the target, or show the aspects of the meshing during the calculation.

2.3. Description of the effects of the penetration.

The important fact resulting from the modelling is the oscillatory character of the pressures and of the stresses in all points of the target and of the projectile.

The first peak pressure (figure 4) corresponds to the initial shock due to the impact and expands on the axis of symmetry of the device in the neighbourhood of the bullet head, in the coating.

This shock, of a significant amplitude (120 kbar), will be very quickly absorbed, on the one hand because of the proximity of the free surfaces that provoke releases in the steel, and on the other hand by a natural divergence during its propagation.

The following oscillations are much more difficult to interpret. Actually several phenomena are working nearly simultaneously :

- the numerous reflections of pressure waves on the free surfaces and on the interfaces may explain the early appearance (5 to 6 μs) of tractions in the coating (of the HOPKINSON effect type);

- similar occurrences take place in the projectile but at different times and with different amplitudes ;

- the projectile penetrates and is distorted in a surrounding that never offers the same resistance, depending upon the spatial localization and the stresses occuring on the place;

- the interfaces and the free surfaces can be distorted or are moving from one another thus complicating the propagation and the reflection of the waves.

These facts, as well as the results obtained, lead to suppose that an effect of pulsation is associated to the penetrating of the bullet, besides this has been noticed by some authors.

2.4. Behavior of the explosive.

Hypothetically the explosive is interdependent of the coating at the interface level. Therefore it is going to undergo the wave train previously created in the steel and absorbed when crossing the line by disadaptation of acoustic impedance.

Figure 5 shows the succession of compressions and tractions modifying the explosive in some points that were initially near the axis and the interface.

It is noted that the maximal amplitude of the pressures is of 10 kbar and that it occurs in the neighborhood of the bullet head when it starts penetrating the explosive.

Previously the pressure never exceeded the value of 4 kbar and this shows that the coating has a function of screening.

2.5. Conclusions.

The comparison of the pressure profiles, calculated with the experimental curve of squibbing by a calibrated shock wave, shows that the direct squibbing of the explosive by a shock wave is most unlikely (figure 6). Indeed, this threshold curve is built with rectangular shocks varying in amplitude between 75 and 25 kbar, whereas the calculated pressures remain at definitely lower levels.

Actually, there remains an uncertainty with regard to the duration of application of the shocks. The calculated intervals of times sometimes clearly exceed the field of validity of the experimental curve, however its asymptotic appearance allows to overlook this uncertainty.

3. EXPERIMENTAL STUDY.

3.1. Search for a configuration.

We have searched for an experimental configuration on a small scale allowing to reproduce the results obtained on a large scale. After some experiments we arrived at the model shown in figure 7.

The model can be defined along the following lines :

- we kept :
  - the nature of the steel of the military warhead
  - the thickness of the steel of the military warhead
  - the static pressure of bursting of the military warhead, this leading us to create planes on the model.

- the mass effect of the explosive is modelled by an anvil placed on the model. The firings showed that the same effects could be observed for the same velocities of the bullet as on a large scale if the mass of this anvil was of 500 kg. The same effects are observed but at higher velocities of the bullet if the mass of the anvil was 250 kg. It is the latter that has been selected because it is easier to implement.

3.2. identifying the parameters that govern the reaction.

The analysis of the experiments realized on a large scale as well as the results obtained after the numerical modelling led us to the conclusion that the reactive mechanism by shock to detonation transition was most unlikely in the configuration in question.

We have therefore worked out a reactive scenario implementing a mechanism of Deflagration to Detonation Transition. This scenario is described in appendix 1. It implies a mechanism of fragmentation of the explosive.

This fragmentation can be of two kinds :

. mechanical : when resulting of the crossing of the bullet

. by cracking combustion : the explosive is fragmented by its own combustion, thus creating favourable conditions for a Deflagration to Detonation Transition.

We have formulated a number of compositions in order to check our reactive scenario.

These compositions are as follows :

Components \ Compositions	A	B	C	D	E
HMX coarse	50 %	50 %	-	76%	-
HMX medium	10 %	11 %	76%	-	-
HMX fine	26 %	27 %	-	-	76%
global content	86 %	88 %	76%	76%	76%
binder	Polyurethane	Polybutadiene	Polyurethane	Polyurethane	Polyurethane

We have characterized them, as regards the mechanical fragmentation, by the test of the "shot gun".

Figure 8 shows the diagram of this test.

The summary of the method is given in appendixes 2 and 3.

The curves of figure 9 describe the obtained results.

They show that :

- all the compositions have not the same behavior to the mechanical fragmentation evaluated by the shot gun test.
- the "coarse" Octogen makes the compositions fragile
- the finer the Octogen, the better the mechanical behavior evaluated by the shot gun test
- the polybutadiene binder improves the behavior of the compositions; it even weakens the harmful effect of the "coarse" Octogen.

These compositions have also been characterized as regards the cracking combustion by the test of burning in high pressure closed vessel (8000 bar). It is observed in that case whether the sample is fragmenting or not by its own combustion and in this way the cracking pressure of the explosive is noted.

The results are summarized in the following table :

Composition	Fragmentation	P Fragmentation (MPa)	dP/dt max. (MPa/ms)
A	yes	170	≃ 1400
B	no	-	≃ 50
C	no	-	≃ 20
D	yes	≃ 250	≃ 530
E	no	-	≃ 13

The compositions that are fragmenting contain "coarse" Octogen.

It appears that the polybutadiene binder weakens the part played by the "coarse" Octogen since the latter enters in the composition B which is not fragmenting.

The diagram of figure 10 gives an example of curves obtained in coordinates V = f (P) on a composition which is fragmenting and on one which is not.

3.3. Firings on models with a 12.7 perforating bullet.

The previously evaluated compositions have been fired in the models defined at par.3.1. The procedure of the firing was as follows :

500 m/s; 740 m/s; 850 m/s; 930 m/s; 1145 m/s with an anvil of 250 kg placed on the model.

The following results were obtained :

Composition → / Impact velocity ↓ (m/s)	A	B	C	D	E
550	nothing to report	nothing to report	nothing to report	noting to report	nothing to report
740	explosion material remaining	opening not much material missing	"	explosion	"
850	id	id	opening not much material missing	id	"
930	stronger explosion	id	id	id	"
1140 250kg	DDT	id	DDT	DDT	"

The compositions that are fragmenting when burning in high pressure vessel and/or that have not as good a behavior as the composition called B to the mechanical fragmentation estimated by the test of the shot gun, lead to a Deflagration to Detonation Transition during the test of firing with a 12.7 P bullet.

The other compositions do not lead to deflagration to detonation transitions. We must point out the particular behavior of the composition E which was not even ignited during the firings with a bullet.

3. PRACTICAL MODEL OF PREDICTION.

This work allowed us to arrive at a first practical model of prediction of the pyrotechnic behavior of a higly confined PBX submitted to a 12.7 P bullet impact.

These will be a high probability of Deflagration to Detonation Transition of a PBX when :

- during the test of burning under high pressure, the composition is fragmenting
- during the test of the shot gun, the composition is showing a curve of evolution of the dP/dt according to the impact velocit, situated above a reference curve that we regard at present as being the composition called "B".
- during the tests of impact on models with a 12.7 P bullet, for velocities from 550 to 1140 m/s, a deflagration to detonation transition is observed.

This practical model of prediction has been worked out from the 5 compositions that are presented here and from the experiments on a large scale that were made until now.

It has furthermore been checked on some other compositions of PBX.

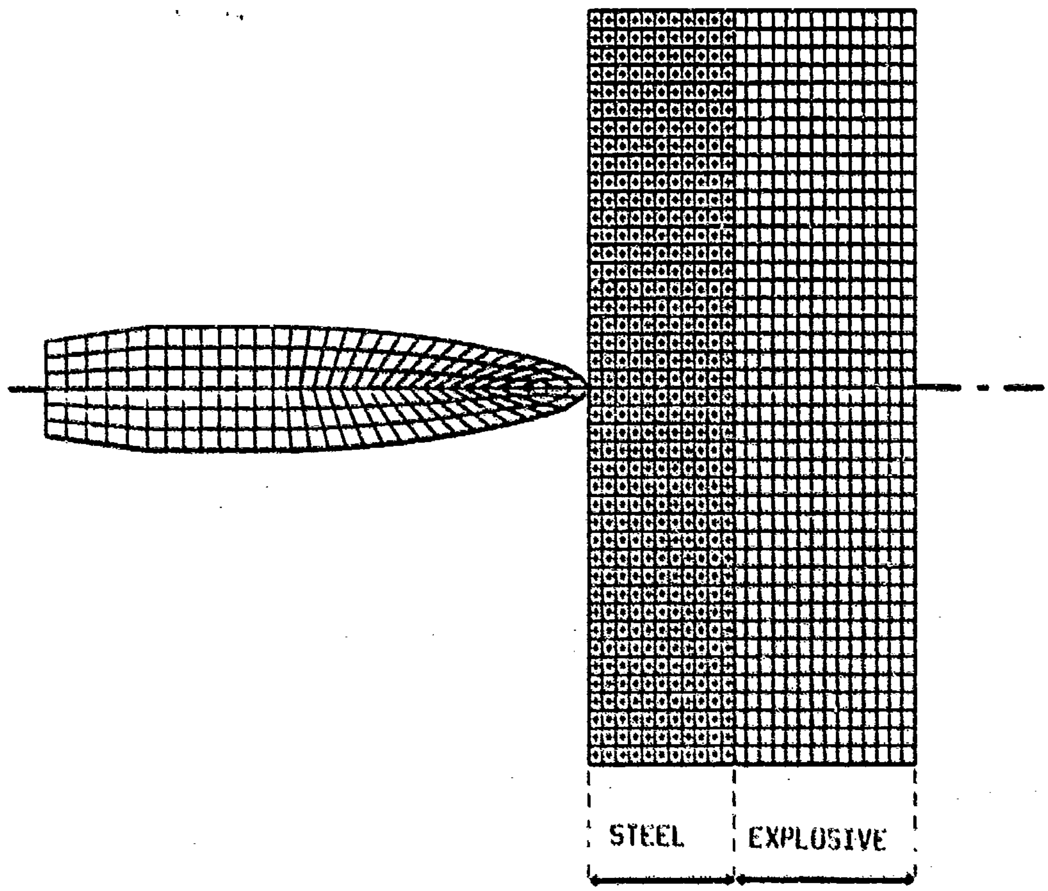
3.4. Conclusion.

This study has led to the realisation of a reactive scenario and we have tried to demonstrate its validity.

We could also develop a first practical model of prediction.

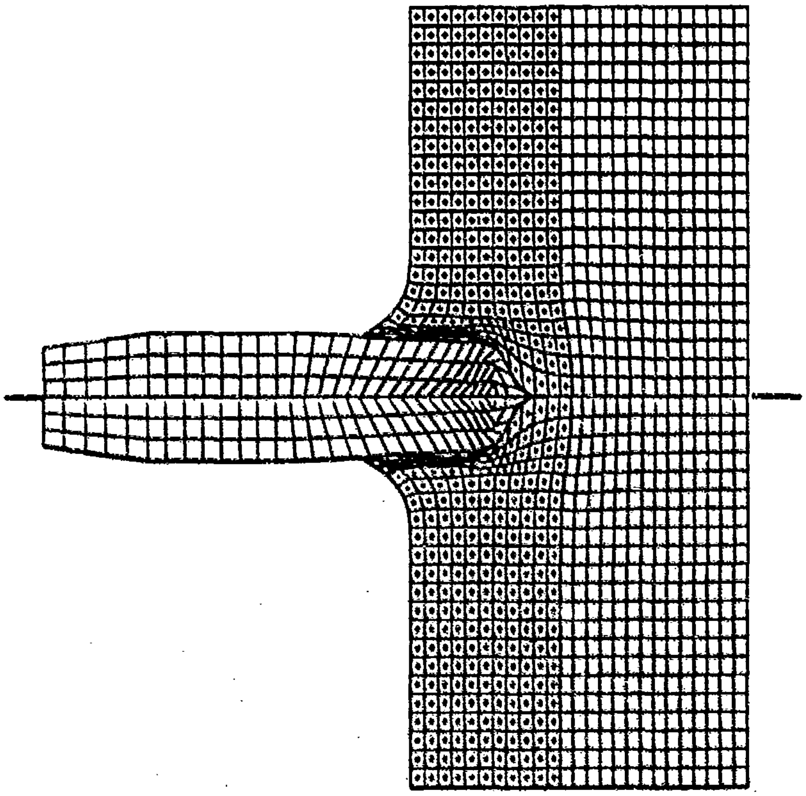
Nevertheless, a considerable work remains to do in order to polish our reactive scenario, to broaden its field of application and to study the directions of research that we can foresee to improve the formulations as regards the stress from the bullet.

- FIGURE 1 -



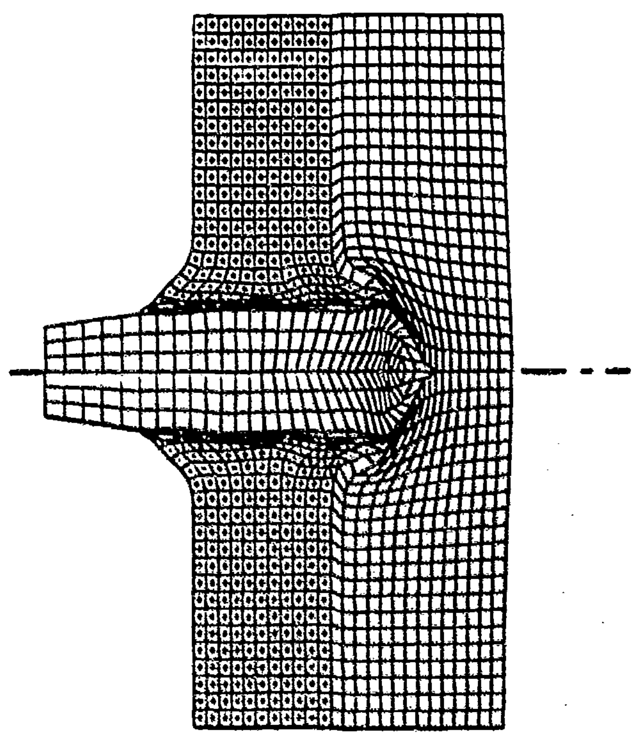
- FIGURE 2 -

PARTIAL VIEW OF THE MESHING A T = 25μs



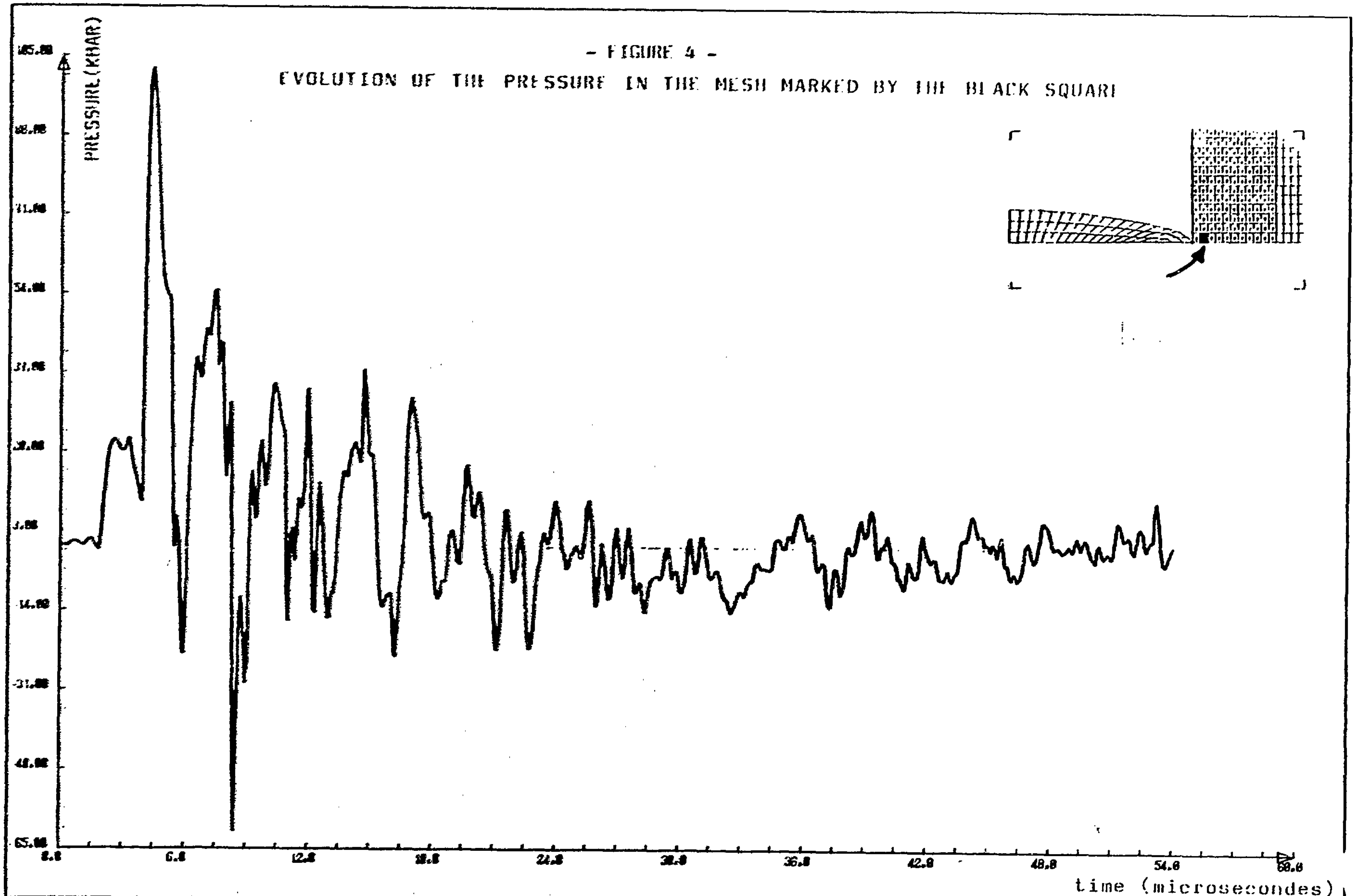
- FIGURE 3 -

PARTIAL VIEW OF THE MESHING : T = 54 μs



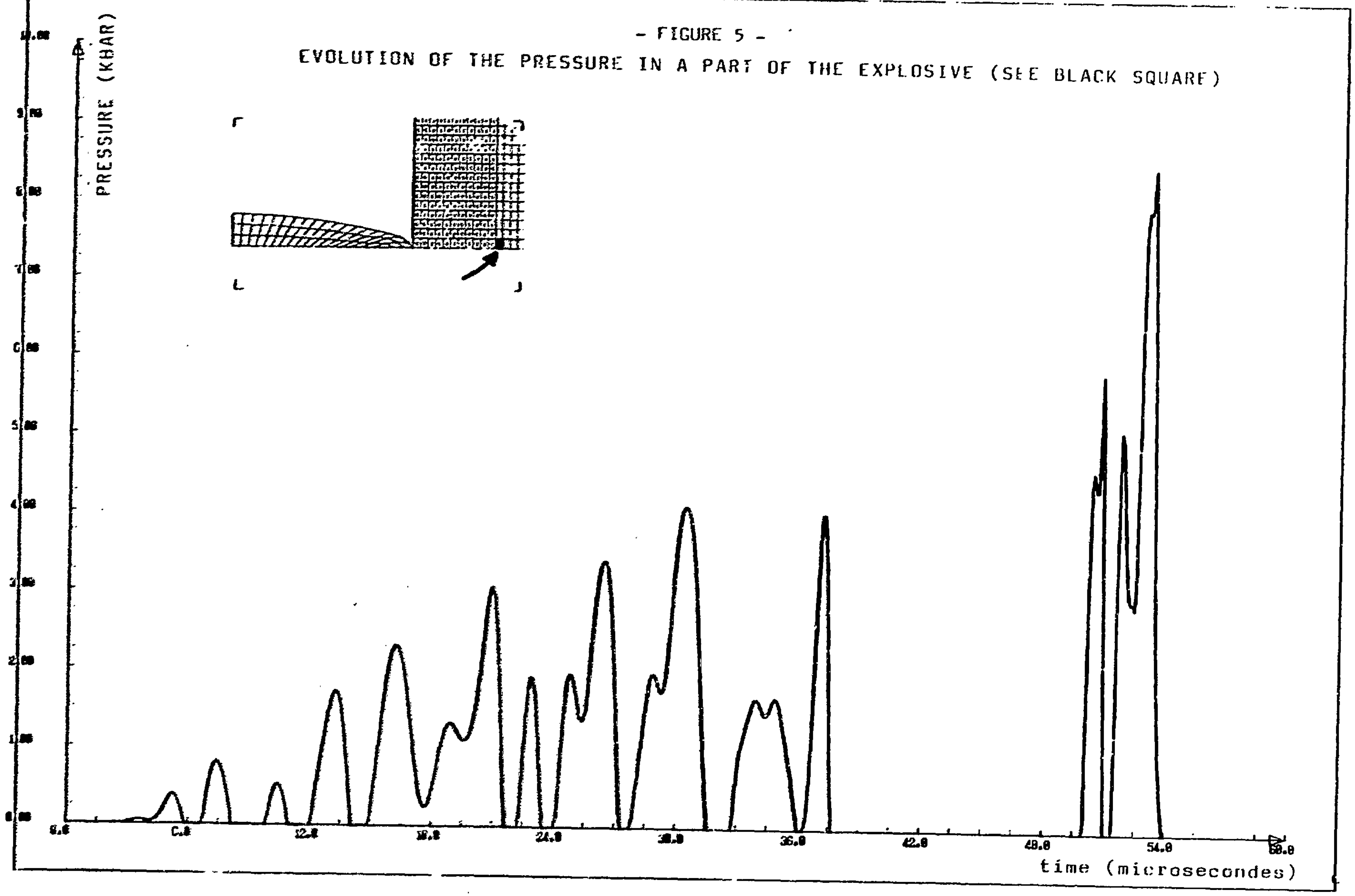
- FIGURE 4 -

EVOLUTION OF THE PRESSURE IN THE MESH MARKED BY THE BLACK SQUARE



- FIGURE 5 -

EVOLUTION OF THE PRESSURE IN A PART OF THE EXPLOSIVE (SEE BLACK SQUARE)



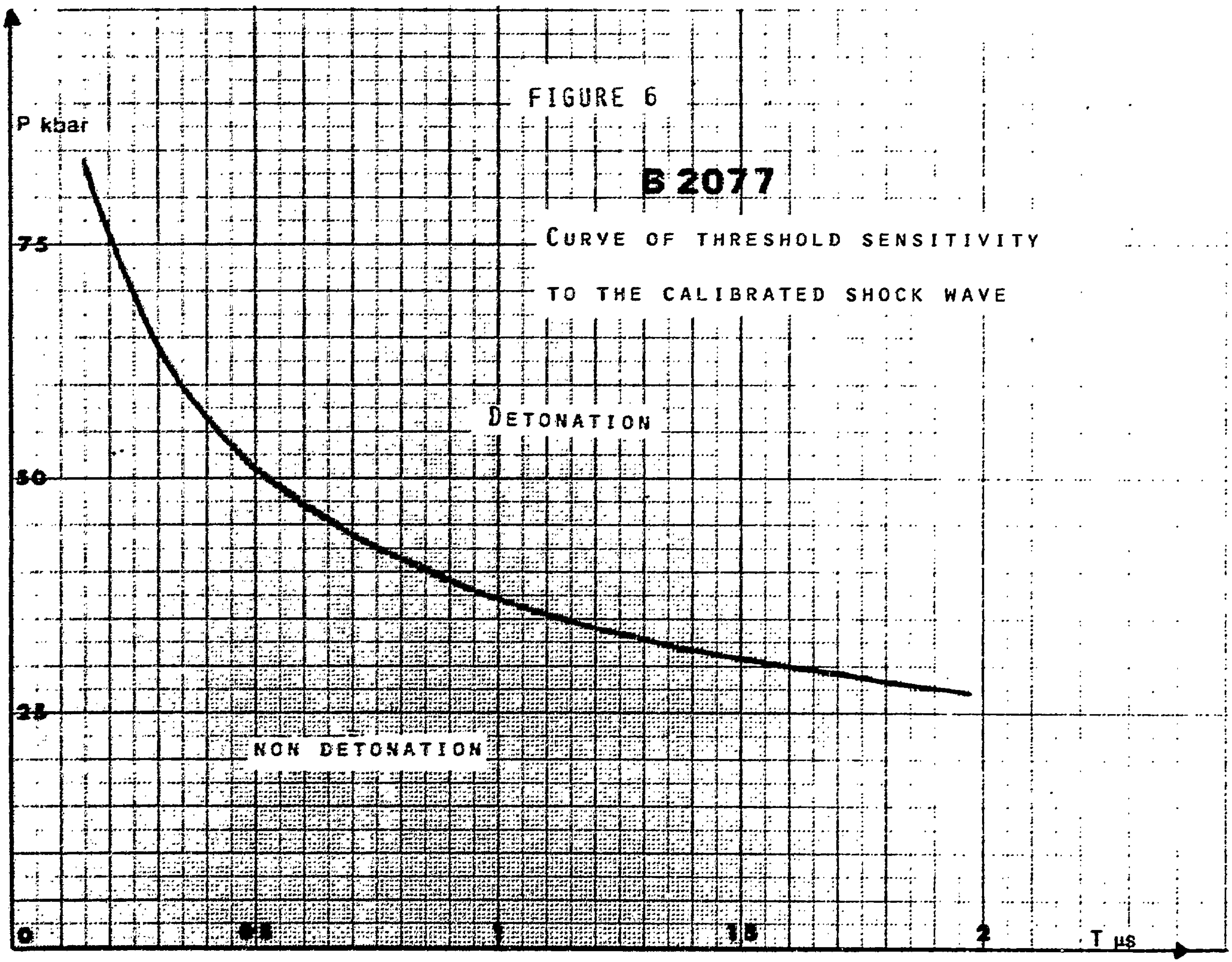


FIGURE 6
B 2077
CURVE OF THRESHOLD SENSITIVITY
TO THE CALIBRATED SHOCK WAVE
P kbar
75
50
25
0
0.5
1
1.5
2
T µs
DETONATION
NON DETONATION

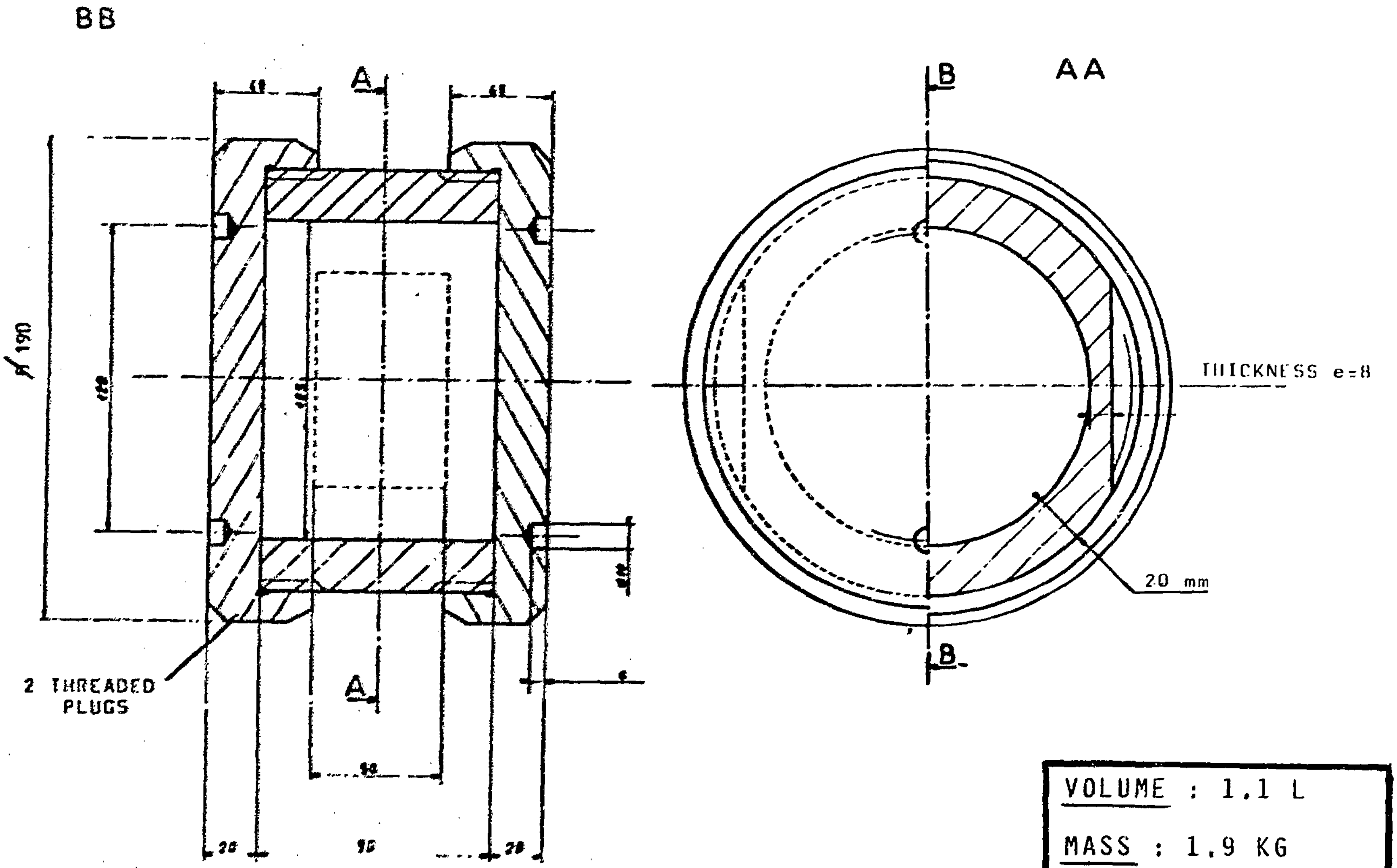


FIGURE 7

VOLUME : 1.1 L

MASS : 1.9 KG

STATIC BURSTING

PRESSURE : 130 MPA

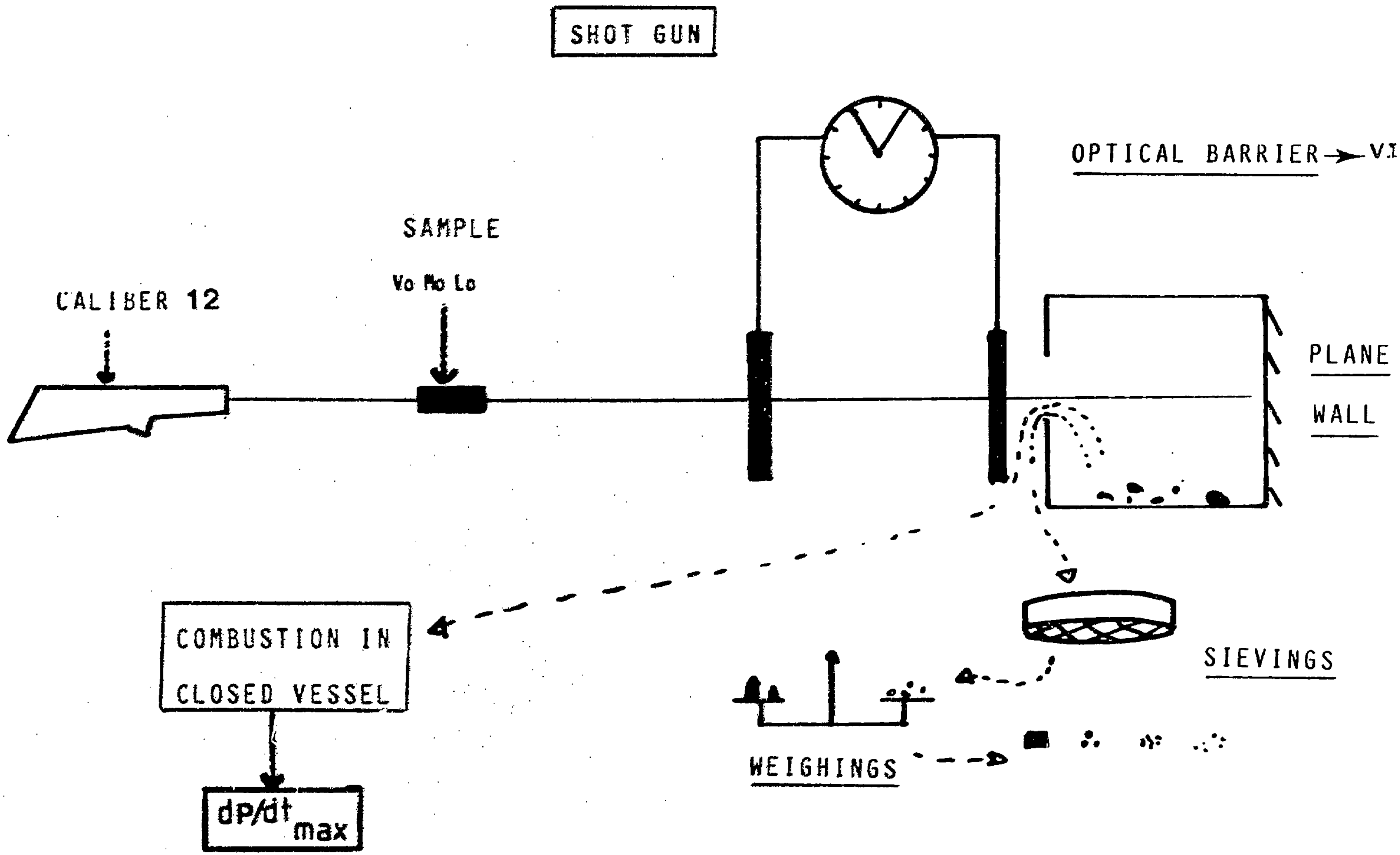

SHOT GUN
OPTICAL BARRIER → V.I
SAMPLE
Vo Mo Lo
CALIBER 12
PLANE
WALL
COMBUSTION IN
CLOSED VESSEL
dP/dt max
SIEVINGS
WEIGHINGS

FIGURE 8

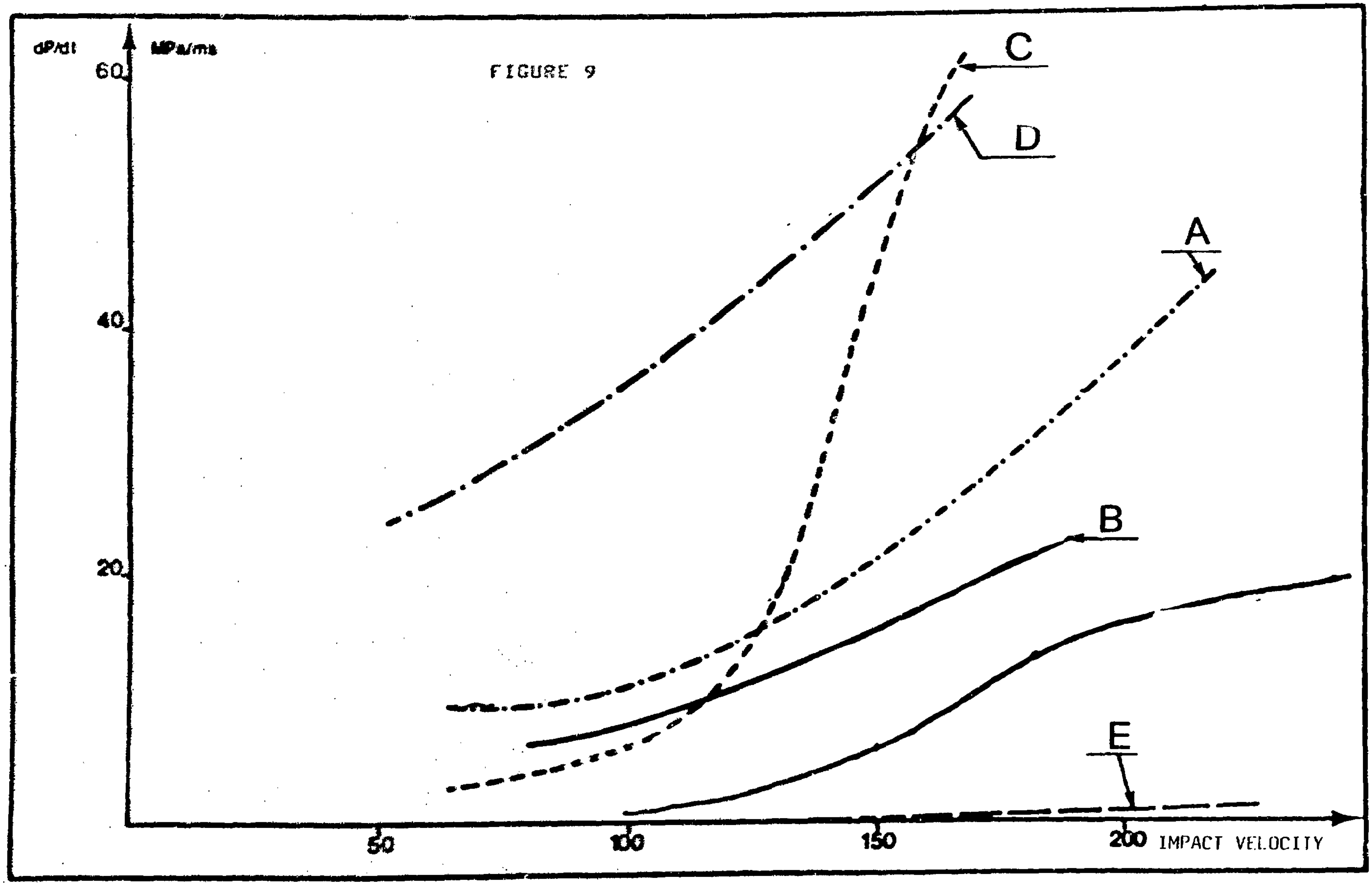
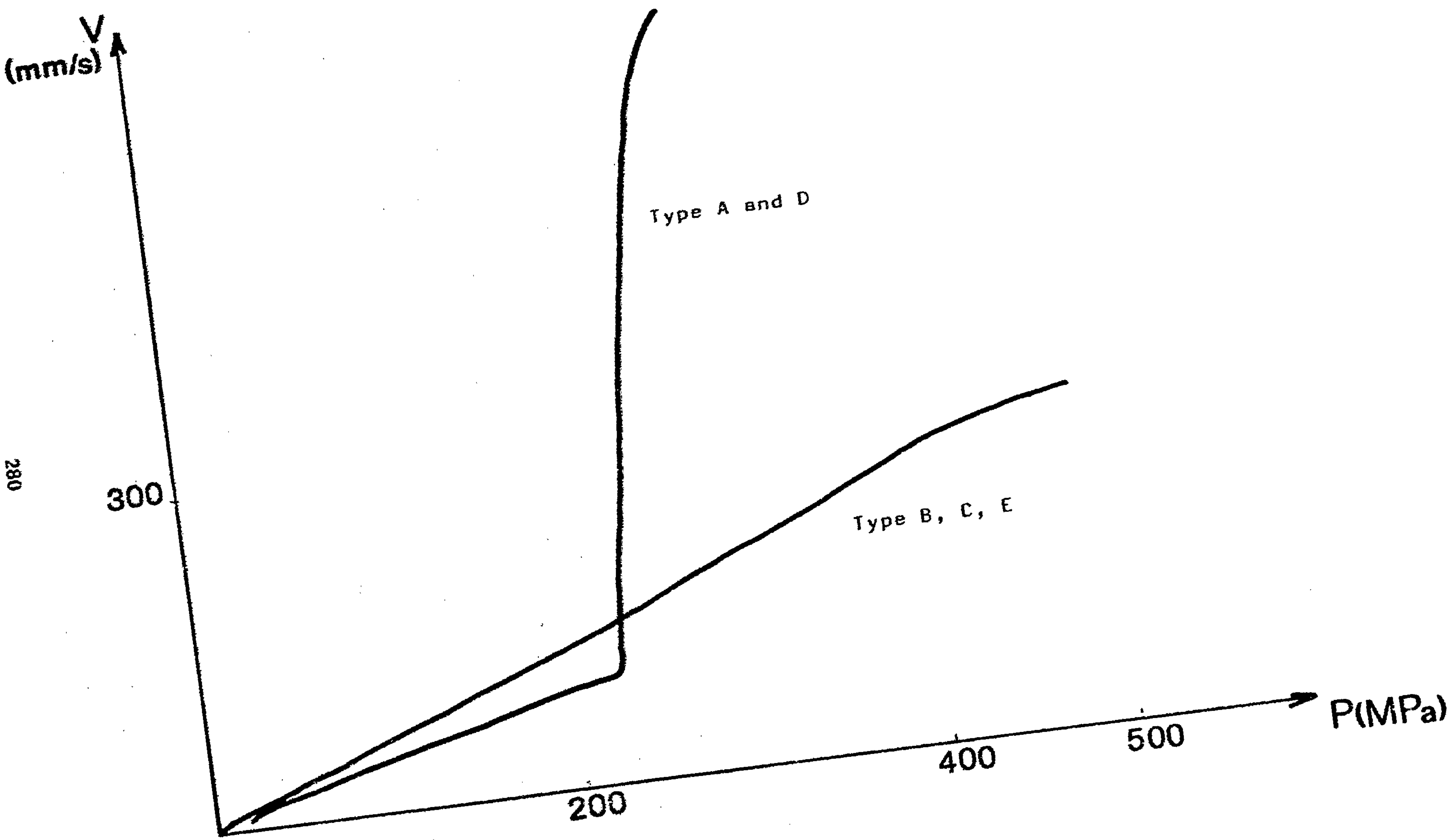


FIGURE 9

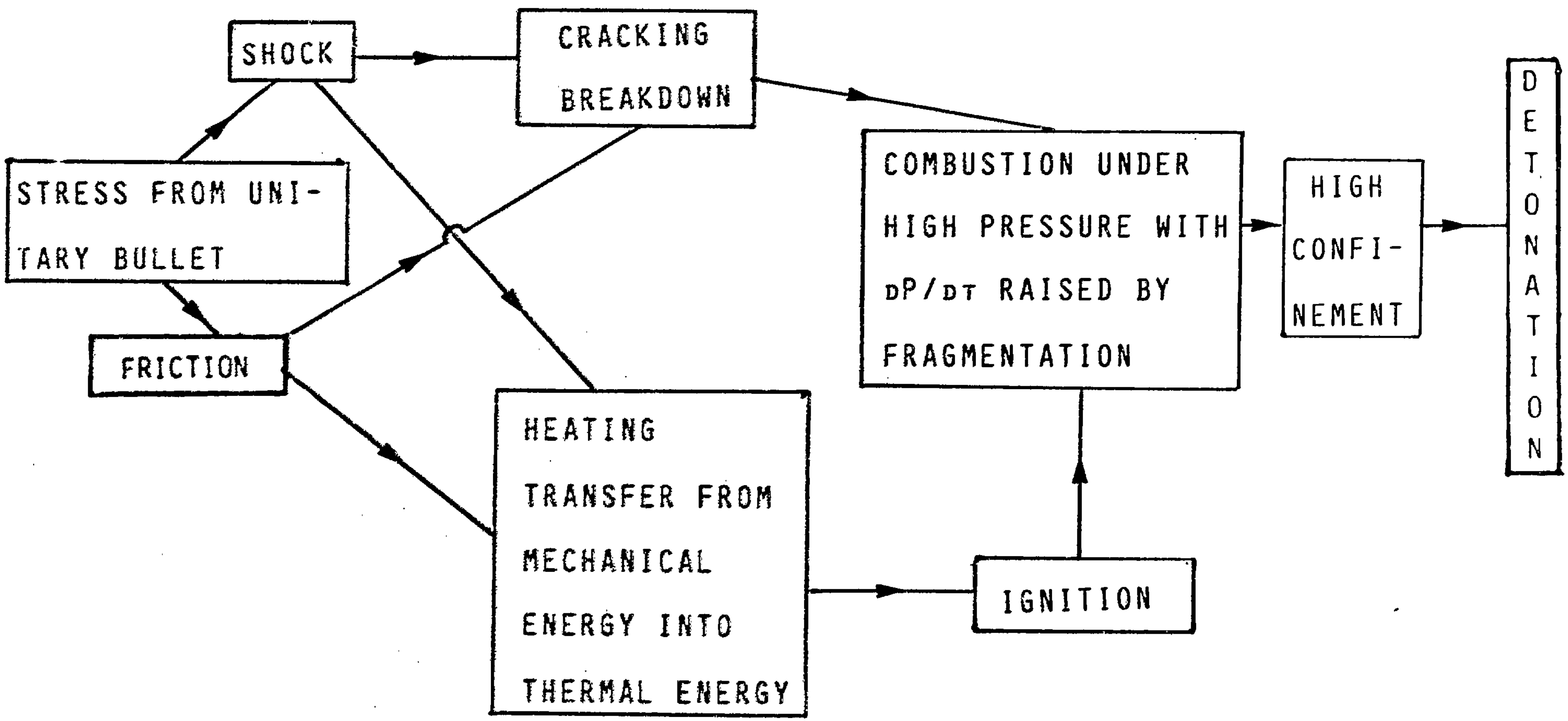
FIGURE 10

V = f(P)



APPENDIX 1

REACTIVE SCENARIO



APPENDIX 2

EXPERIMENTS NETWORK Test n°82-01/01	PROJECTION OF A FREE BLOCK ON A PLANE WALL	SNPE/CRB Service TB January 1983

FAMILY OF THE MATERIALS : PBXs.

PRINCIPLE.

A sample of explosive, in the form of a small cylinder, is thrown on a steel (plane) wall.

The degree of fragmentation of the material or, as the case may be, the type of reaction from the moment of the impact, is observed according to the velocity of projection of the cylinder.

THE ESSENTIAL POINTS OF THE TEST.

The cylinders of explosive are 18 mm in diameter; their length is adjusted when manufactured so that a mass of 9 grams is obtained.

The test cylinder is placed at the front of a cartridge charged in order to obtain the value of the desired impact velocity.

For a given material and for a conditioning temperature, various samples are thrown in order to have :

a) either the velocity under which there is no pyrotechnic occurence (confirmed by 3 negative tests)

b) or the evolution of the decohesion.

The characterization of the decohesion level can be made either with the codified test n°49 "combustion of fragments in closed vessel" or with a granulometric analysis of the collected fragments.

CODIFIED RESULTS.

Reference of the PBX	Temperature of the sample in C°	Impact velocity of pyrotechnic non-reaction	Type of reaction observed at higher velocity	Reference of the test sheet

SHORT TITLE OF THE TEST : IMPACT ON A PLANE WALL.

APPENDIX 3

EXPERIMENTS NETWORK Test n°49-01/01	COMBUSTION OF FRAGMENTS IN CLOSED VESSEL	SNPE/CRB Service TB January 1983

FAMILY OF THE MATERIALS : PBXs.

PRINCIPLE.

A certain amount of PBX in a fragmented form is burnt in a pressure resistant vessel, of constant volume.

The evolution of the pressure inside the vessel according to the time is recorded. The maximal value of dP/dt is researched.

THE ESSENTIAL POINTS OF THE TEST.

The vessel has a volume of 90 cm3 and is used at a density of charge of : $\Delta = 0{,}1$ g/cm3.

The ignition is made with a hot wire and a relay bag of black powder of 0,5 g.

The recording of the pressure is obtained with a piezo electric sensor and an associated numerical recording chain. P = f (t) and dP/dt = f (P/Pmax) is recorded as well as ti (time taken by the pressure to go from 0 to 30 bar) ans tc (time taken by the pressure to go from 30 bar to Pmax).

CODIFIED RESULTS.

Reference of the PBX	Method for obtaining the product	Temperature of the sample before the impact if necessary	$\frac{dP}{dt}_{max}$	Reference of the test sheet.

SHORT TITLE OF THE TEST : COMBUSTION IN CLOSED VESSEL.